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Value-Added Products from Extruding-Expelling of Soybeans

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Abstract

Increasingly, extruding-expelling (E-E) plants, often referred as "mini-mills," are being constructed by farmer-owned businesses to process soybeans produced in local areas. E-E processing is a mechanical process that has several advantages over conventional processing methods. E-E mills, most employing the Express System® (Insta-Pro Div., Triple "F", Inc., Des Moines, IA), are relatively small, with capacities ranging from 6 to 120 tons/day. They have low initial capital investment ($150,000–200,000) and relatively low operating costs ($25/ton) (1). E-E mills are especially well suited for processing identity-preserved (IP) soybeans. The largescale solvent extraction (SE) facilities, which have typical crushing capacities of 2,000 to 3,000 tons/day, are not feasible for flexible IP processing. Usually, there is low production tonnage during the developmental stages of these seeds, and a large number of value-added traits are being developed. Recent stringent environmental laws also often restrict construction of new SE plants, and E-E mills can be an alternative. Because E-E products are not treated with chemical solvents, the crude oil and meal may be considered to be "organic" or "natural," if appropriate methods are used during soybean production and further processing. Currently, the partially defatted soybean flour (about 6% residual oil) produced from these operations is not extensively used in food applications due to limited technical information on protein functionality and on performance in food applications. Some of the potential applications include baking, meat extending, animal feeding, and producing industrial soy protein–based adhesives. This chapter summarizes the recent efforts aimed at improving E-E processing and developing applications for E-E protein products.

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Chapter 9

Value-Added Products from Extruding-Expelling of Soybeans

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Increasingly, extruding-expelling (E-E) plants, often referred as “mini-mills,” are being constructed by farmer-owned businesses to process soybeans produced in local areas. E-E processing is a mechanical process that has several advantages over conventional processing methods. E-E mills, most employing the Express System® (Insta-Pro Div., Triple “F”, Inc., Des Moines, IA), are relatively small, with capacities ranging from 6 to 120 tons/day. They have low initial capital investment ($150,000–200,000) and relatively low operating costs ($25/ton) (1). E-E mills are especially well suited for processing identity-preserved (IP) soybeans. The large-scale solvent extraction (SE) facilities, which have typical crushing capacities of 2,000 to 3,000 tons/day, are not feasible for flexible IP processing. Usually, there is low production tonnage during the developmental stages of these seeds, and a large number of value-added traits are being developed. Recent stringent environmental laws also often restrict construction of new SE plants, and E-E mills can be an alternative. Because E-E products are not treated with chemical solvents, the crude oil and meal may be considered to be “organic” or “natural,” if appropriate methods are used during soybean production and further processing. Currently, the partially defatted soybean flour (about 6% residual oil) produced from these operations is not extensively used in food applications due to limited technical information on protein functionality and on performance in food applications. Some of the potential applications include baking, meat extending, animal feeding, and producing industrial soy protein–based adhesives. This chapter summarizes the recent efforts aimed at improving E-E processing and developing applications for E-E protein products.

E-E Process

In E-E processing, dry extrusion is used as a shearing and heating pretreatment to disrupt the cellular organization of the seed and free the oil. An expeller or screw press is then used to press out the oil. The extruder, as used for many years in the food industry, consists of a flighted screw that rotates in a tight-fitting barrel to convey and compress the feed material, which is pressed into a dough-like material. As the material progresses toward the die, both temperature and pressure increase as a result of the relatively shallow screw flights and increased restriction. The sudden pressure drop as the product is forced through the die causes expansion of the extrudate. Entrapped water vaporizes or "flashes off" due to the high internal temperature. All of these events cause disruption of cell walls and subcellular organizations and denaturation of proteins, and free the oil held in spherosomes.

Dry extrusion processing of soybeans was developed in the 1960s to enable Midwestern U.S. soybean growers to cook soybeans for use as livestock feed right on the farm where the soybeans were produced (1). The process uses friction as the sole source of heat to deactivate the antinutritional factors present in oilseeds. This type of extruder typically uses a three-segment screw with intervening steam or shear locks to prevent backflow of steam and molten product and to increase shear. The product prepared from whole soybeans is a dry extrudate with an average of 38% crude protein and 18% oil, and has been successfully used in high-energy diets for livestock. On the other hand, continuous screw pressing (SP) or expelling, the major soybean processing technique before World War II, had relatively low oil-removal efficiency, leaving 4–8% residual oil (RO). This mechanical method was largely replaced by SE.

Coupling dry extrusion and expelling was first reported by Nelson *et al.* (2) at the University of Illinois for processing soybeans to obtain good quality oil and meal high in protein. A process flow diagram for E-E processing is shown in Figure 9.1. In the method of Nelson *et al.* (2), the coarsely ground whole soybeans with 10–14% moisture content were extrusion cooked. The residence time in the extruder was less than 30 seconds, and the internal temperature was about 135°C. The extrudate that emerges from the die was a hot semi-fluid and was immediately pressed in a continuous screw press. Extruding prior to SP greatly increased the throughput of the expeller. About 70% oil recovery was obtained in single-pass expelling. Press cake with about 50% protein, 6% RO, and 90% inactivation of trypsin inhibitor (TI) was obtained from dehulled soybeans. The high-temperature, short-duration heat treatment of extrusion successfully replaced prolonged heating and holding of raw materials as practiced in conventional SP operations.

Bargale *et al.* (3) also used E-E processing to process soybeans. Three different types of extruders and processing conditions were used to enhance oil recovery. Pressing variables, such as pressure, temperature, and sample height, were studied using a hydraulic press. Over 90% of the available oil could be recovered by using extrusion as pretreatment for batch pressing.

Qualities of Meals and Oils Produced by E-E, SP, and SE

Soybean oil and meal produced by E-E processing have unique characteristics compared with products produced by SE. Wang and Johnson (4) compared quality characteristics of oils and meals produced from different types of soybean processing methods. Soybean oil and meal samples were collected three different times over a one-year period from 13 E-E mills, eight SE plants, and one continuous SP plant. The quality characteristics of the soybean meals are presented in Table 9.1. SP was

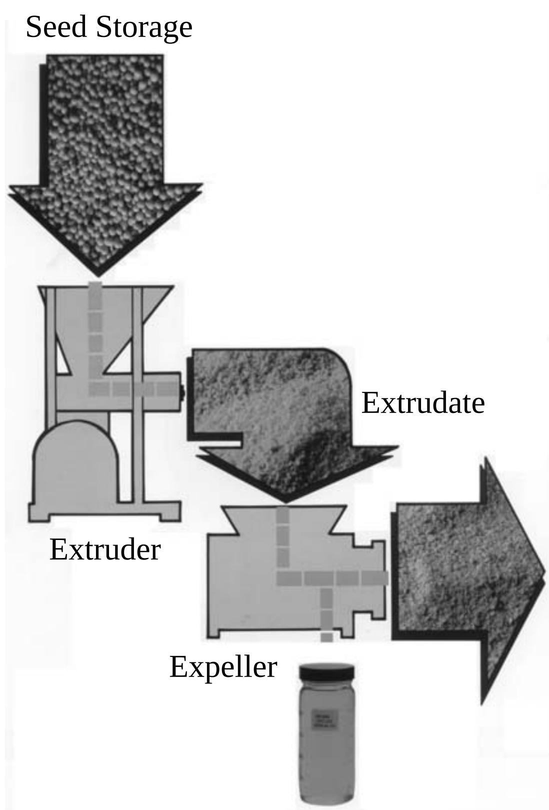


Figure 9.1. Extruding-expelling (E-E) system used for soybean processing (adapted from Insta-Pro International product brochure).

slightly more efficient in recovering oil than was E-E processing, leaving 6.3% oil compared with a mean of 7.2% for E-E meals. These values were considerably higher than those for SE meals (1.2%).

The degree of protein denaturation in soybean meal is typically measured by determining protein solubility under alkaline (KOH) conditions, urease activity, and protein dispersibility index (PDI). KOH protein solubilities of E-E and SE meals were not significantly different, nor were urease activities, indicating that the amounts of heat exposure for feed purposes were equivalent. SP meals had an average of 61.6% KOH protein solubility and 0.03 pH units of urease activity, suggesting much greater protein denaturation. PDI values of E-E meals (mean of 18.1) were much lower than those of the SE meals (mean of 44.5), indicating higher degrees of protein denaturation were achieved in E-E processing. Relationships between PDI and KOH protein solubilities were different between E-E and SE meals (Fig. 9.2).

TABLE 9.1
Quality Characteristics of Soybean Meals Produced by Extruding-Expelling (E-E), Solvent Extraction (SE), and Screw-Press (SP) (4)[a]

	E-E		SE		SP	
Moisture, %	6.9	b	11.7	a	11.0	a
Oil, %[b]	7.2	a	1.2	b	6.3	a
Protein, %[b]	42.5	b	48.8	a	43.2	b
Fiber, %[b]	5.4	a	3.7	b	5.9	a
Urease, ΔpH	0.07	a	0.04	a	0.03	a
KOH solubility, %	88.1	a	89.1	a	61.6	b
PDI[c]	18.1	b	44.5	a	10.6	c
Rumen bypass, %	37.6	b	36.0	b	48.1	a
Trypsin inhibitor, mg/g	5.5		5.5		0.3	

[a]The values in the same row with different letters are significantly different at 95% confidence level.
[b]Percentages are based on 12% moisture content.
[c]Protein Dispersibility Index.

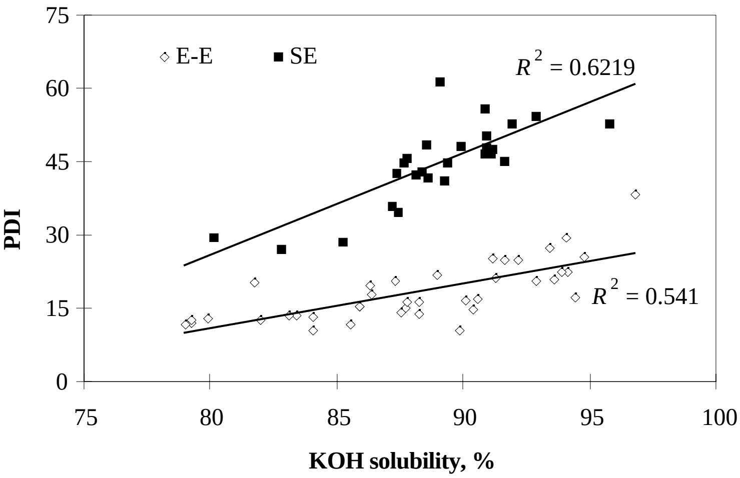


Figure 9.2. Relationship between protein dispersibility index (PDI) and KOH protein solubility of soybean meals (4).

Rumen-bypass or rumen-undegradable protein (RUP) is an important measure of potential protein utilization by ruminant animals. A higher RUP indicaties that more protein will escape rumen bacterial fermentation and will be utilized by the animals. An ammonia-release procedure was used for RUP determination (5). RUP values were similar for E-E and SE meals (37.6 versus 36.0%, respectively), which have different degrees of protein denaturation as measured by PDI. Figure 9.3 shows a scatter plot of RUP versus PDI. E-E meals, which had more protein denaturation

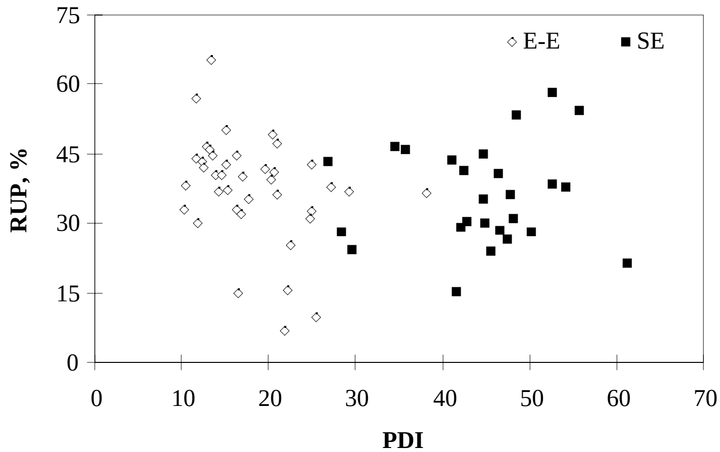


Figure 9.3. Relationship between protein dispersibility index (PDI) and rumen undegradable protein (RUP) of soybean meals (4).

than SE meals (as shown by low PDI), should have had higher RUP values. But the very brief heat exposure of E-E processing (about 30 seconds) at low moisture content may not have produced the kind of protein denaturation needed to pass the rumen intact. It is common practice to hold the beans at elevated temperatures after roasting to allow more thorough heat treatment in order to produce feed ingredients with high RUP for lactating dairy cows. By carefully examining the scatter plot, a general trend could be identified. There seemed to be a minimum RUP value at a PDI value of approximately 30. Below this PDI, the lower the PDI, the higher the RUP values; above this PDI, the higher the PDI, the higher the RUP values. When inadequately denatured, the protein may not be readily available to rumen bacteria; therefore, a higher percentage of the protein passes through the rumen.

TI activity is an important quality parameter of soybean meal, especially when the meal is fed to monogastric animals. Urease activity is usually used as an indicator for TI activity. There are no differences in urease activity or TI activity between E-E and SE meals, and the low values suggest that the antinutritional factors have been sufficiently inactivated.

The essential amino acid compositions of soybean meals processed by different methods are shown in Table 9.2. Arginine, cysteine, and lysine percentages in SP meal were considerably lower than for the soybean meals processed by other processing methods, suggesting degradation of these amino acids under severe heat treatment. Heating generally increases digestibility of amino acids. But when exposed to excessive heat, the amino acid digestibility could be reduced, especially for lysine and cysteine (6). The amino acid composition data in this report are similar to those of Baize (7).

The qualities of E-E, SE, and SP soybean oils are compared in Table 9.3. Peroxide value (PV) is a measure of primary lipid oxidation products in the oil. The

TABLE 9.2
Essential Amino Acid Compositions of Soybean Meals in Percent of Total Protein (4)[a]

Amino Acid	E-E	SE	SP
Arginine	7.45 a	7.56 a	7.27 b
Cysteine	1.73 a	1.60 b	1.51 b
Histidine	2.77 a	2.76 a	2.75 a
Isoleucine	4.64 ab	4.54 b	4.70 a
Leucine	7.92 b	7.92 b	8.03 a
Lysine	6.50 a	6.49 a	6.01 b
Methionine	1.49 ab	1.48 b	1.54 a
Phenylalanine	5.18 a	5.15 a	5.21 a
Tyrosine	3.60 a	3.59 a	3.60 a
Threonine	3.94 a	3.97 a	4.01 a
Tryptophan	1.47 a	1.44 a	1.45 a

[a]The values in any row with different letters are significantly different at 5%.

TABLE 9.3
Quality Characteristics of Soybean Oils Produced from Extruding-Expelling (E-E), Solvent Extracting (SE), and Screw Press (SP) (4)[a]

	E-E	SE	SP
PV, meq/kg	1.73 a	0.96 b	1.76 a
FFA, %	0.21 b	0.31 ab	0.33 a
Phosphorus, ppm	75 c	277 b	463 a
AOM[b] stability, h	23.9 b	39.8 a	36.2 a
Moisture, %	0.08 a	0.08 a	0.05 b
Tocopherols, ppm	1257 b	1365 a	1217 b
Color, red	10.2 b	11.1 b	17.5 a

[a]The values with different letters in the same row are significantly different at 95% confidence level.
[b]Active oxygen method.

PVs of the crude E-E oils (mean of 1.73 meq/kg) were significantly higher than those of crude SE oils (mean of 0.96 meq/kg), which was attributed to the high temperature used in the E-E process, the long period allowed for oil cooling, and/or the poor oil storage conditions and longer storage times at the E-E mills. Crude SP oil (1.76 meq/kg) had a similar PV as the mean for E-E oils. Free fatty acid (FFA) content is a measure of hydrolytic degradation during seed storage and oil extraction, and higher FFA values result in higher refining losses during subsequent oil refining. The FFA contents of E-E processed oils (mean of 0.21%) were significantly lower than those of SE oils (mean of 0.31%), which may be due to the rapid inactivation of lipases during extrusion. SP oil contained 0.33% FFA, which was similar to that of SE oils.

Phospholipids (PLs), also referred to as gums or lecithin, are polar lipids in the oil. PL contents of the oils after natural settling were much lower in E-E oils (mean of 75 ppm phosphorus) than in SE oils (mean of 277 ppm phosphorus). SP oil had much higher PL content (463 ppm phosphorus) than did SE oil. The PLs in E-E oils were more hydratable and easier to settle; these properties were attributed to the rapid heat inactivation of the phospholipases. Tocopherols are a group of natural compounds possessing antioxidant activity. Their concentration and composition influence the oxidative stability of the oil. Total tocopherol contents of the E-E oils were slightly, but statistically and significantly, lower than those of the SE oils (mean of 1,257 versus 1,365 ppm). Oxidative stabilities, as measured by the active oxygen method (AOM), of the E-E oils (mean of 23.9 hours) were significantly lower than those of the SE oils (mean of 39.8 hours), probably due to the higher PVs and lower contents of phosphorus and tocopherol in E-E oils. The AOM value of the SP oil (mean of 36.2 hours) was greater than that of E-E oil due to its higher PL content, but less than that of the SE oils. The colors of the E-E (mean of 10.2 red) and SE (mean of 11.2 red) oils were not statistically different, although SE oils tended to be slightly darker than E-E oils. SP oil (17.4 red) was much darker in color than the other two types of oils, probably due to the more severe heat treatment before pressing.

Characteristics of E-E Meals Produced under Various Processing Conditions

Currently, the partially defatted E-E soy flour (ground E-E meal) is not extensively used in mainstream food products, because little information is available about its functionality and potential in food applications. One potential use of partially defatted soy flour is the production of texturized vegetable protein (TVP). However, it is believed that partially defatted soy flour will perform much differently in TVP production than the traditionally defatted soy flours because of the extensively heat-denatured protein and high oil content. Crowe *et al.* (8) and Heywood *et al.* (9) studied the range of PDI and residual oil content that could be produced by E-E processing, and characterized the functionalities of these partially defatted soy flours.

In the Crowe *et al.* study, soybeans were processed using an Insta-Pro 2500 extruder and an Insta-Pro 1500 screw press (Insta-Pro Div., Triple "F", Inc., Des Moines, IA). The extruder temperature was adjusted by manipulating the screw design and shear-lock configuration, as well as the die (nose cone) restriction. SP conditions were modified by changing choke settings. Partially defatted soy flours having a wide range of PDI values (12.5 to 69.1) and RO contents (4.7 to 12.7%) were achieved by changing extruder and SP operating conditions. The relationships between residual oil (RO) content and PDI, and between extruder temperature (zone 1, the highest temperature region) and PDI or TI activity are shown in Figures 9.4 and 9.5. PDI correlated with RO content and extruder temperature.

TI activities ranged from 4.5 to 97.5% of the activity of raw soybeans and decreased with increasing extruder barrel temperature. Guzman *et al.* (10) varied

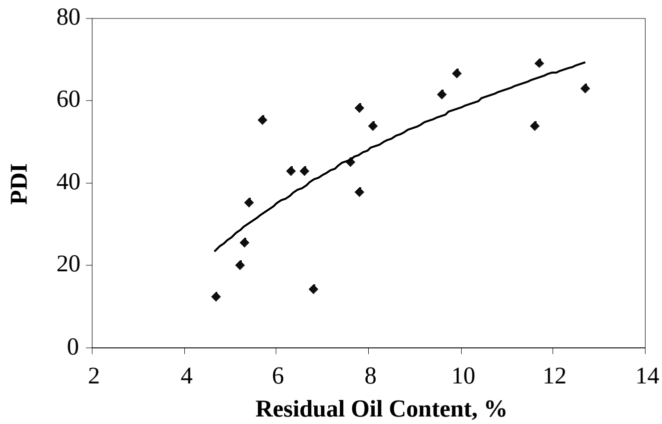


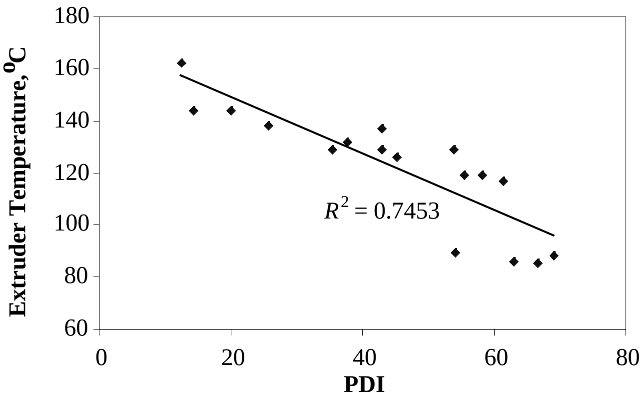
Figure 9.4. Relationship between protein denaturation (PDI) and residual oil content of E-E meals (8).

extrusion temperatures from 127 to 160°C and reported that residual TI activities in non-expelled samples were between 2 and 31% of the original activity. The activities of all three lipoxygenase isozymes (L1, L2, and L3) decreased with increasing temperature and were not detectable in most of the partially defatted soy flours when the extruder temperature was greater than 89°C (8).

Functionalities of E-E Flours Produced under Various Processing Conditions

The low-fat soy flours (LFSF) obtained as described above can be grouped into three PDI/RO categories: low PDI/RO (14.3 ± 5.0/6.8 ± 0, designated as low LFSF), mid-range PDI/RO (41.6 ± 3.0/7.8 ± 1.8, mid LFSF), and high PDI/RO (66.6 ± 4.0/11.2 ± 1.5, high LFSF). Functionality of each of the flours was compared with the functionality of a commercial defatted soy flour (DFSF) by Heywood *et al.* (9). Functionality tests included solubility, emulsification capacity (EC), emulsification activity index (EAI), emulsion stability index (ESI), foaming capacity (FC), foam stability (FS), water-holding capacity (WHC), and fat-binding capacity (FBC).

Protein solubility curves for different E-E flours are compared in Figure 9.6. All three LFSFs and the DFSF had minimum solubility at pH 4.0 and the solubility increased with more basic or more acidic pH, and those receiving more heat treatment had modestly less protein solubility than those receiving less heat treatment. Protein solubility is considered to be one of the most important measures of functionality, because it is an indicator of how the protein will perform in other functionality tests (11). The ECs of the E-E flours are shown in Figure 9.7. EC increased with increas-



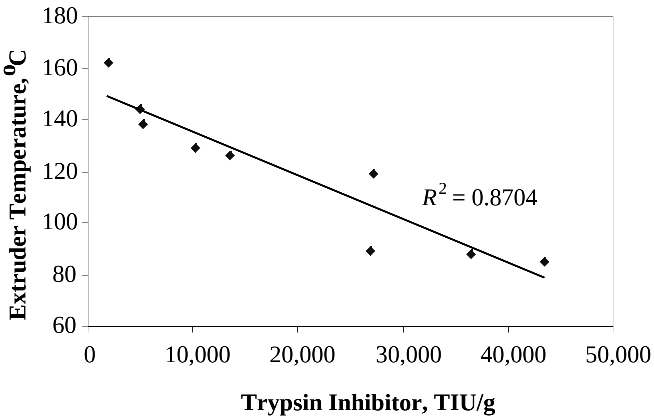


Figure 9.5. Relationship between extruder temperature and denaturation of soy protein and trypsin inhibitor (8).

ing pH and PDI/RO. As the pH approaches the protein's isoelectric point, pI, net electrical charge decreases, reducing solubility and functionality. This was more obvious for the more heat-denatured protein flours.

EAI is a measure of the interfacial area that is stabilized per unit weight of protein. ESI is a measure of the resistance of an emulsion to breakdown. EAI has been found to be highest for low LFSF and lowest for DFSF (Table 9.4). The ESI follows the same trend as EAI. EAI directly relates to oil globule size, and therefore, low LFSF may have resulted in the smallest oil globule size, resulting in the greatest ESI.

WHC was significantly lower for the high LFSF compared with the other samples. This result was attributed to the large amount of RO present in high LFSF.

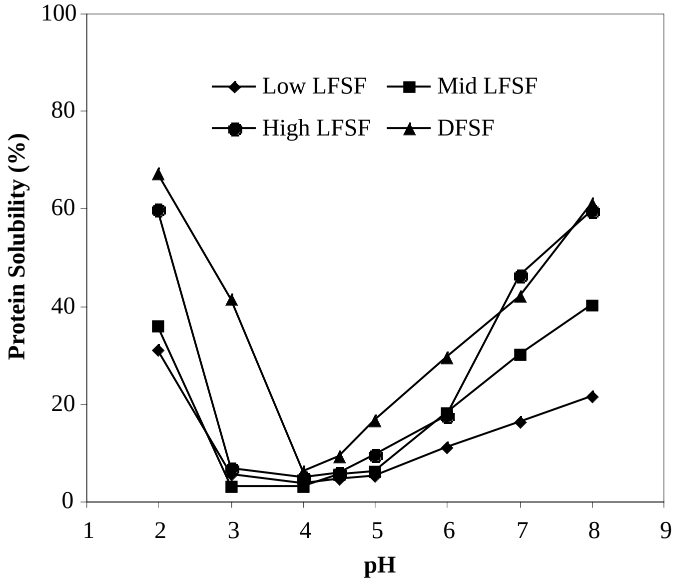


Figure 9.6. Protein solubility curves for low-fat soy flours (LFSF) and defatted soy flour (DFSF) (9).

TABLE 9.4
Functional Properties of Various Soy Flours (9)[a]

Treatment	EAI[b]	ESI[c]	WHC[d]	FBC[e]	FC[f]	FS[g]
Low LFSF	15.4 b	12.78 a	6.75 a	1.66 b	0.81 c	0.37 a
Mid LFSF	12.1 a	11.35 b	6.19 a	1.74 b	0.85 a	0.14 b
High LFSF	11.2 a	10.28 c	4.79 b	1.84 b	0.88 b	0.11 c
DFSF	10.8 a	10.36 bc	6.70 a	2.22 a	0.85 a	0.01 d

[a]Values followed by same letter in the same column are not significantly different at 95% confidence level.
[b]Emulsification activity index, in m^2g^{-1}.
[c]Emulsion stability index, in min.
[d]Water-holding capacity, g water/g protein.
[e]Fat-binding capacity, g oil/g protein.
[f]Foaming capacity, mL foam/mL N^2 × min.
[g]Foam stability, mL^{-1} × min^{-1}.

DFSF had much higher fat-binding capacity than the LFSF. Residual oil that was present in LFSF may have blocked the hydrophobic binding sites usually available for binding added fat.

FC is a measure of the maximum volume of foam generated by a protein solution, while FS is a measure of the resistance of the foam to destabilization and collapse. The lower the value, the more stable the foam. DFSF and LFSF had significantly different

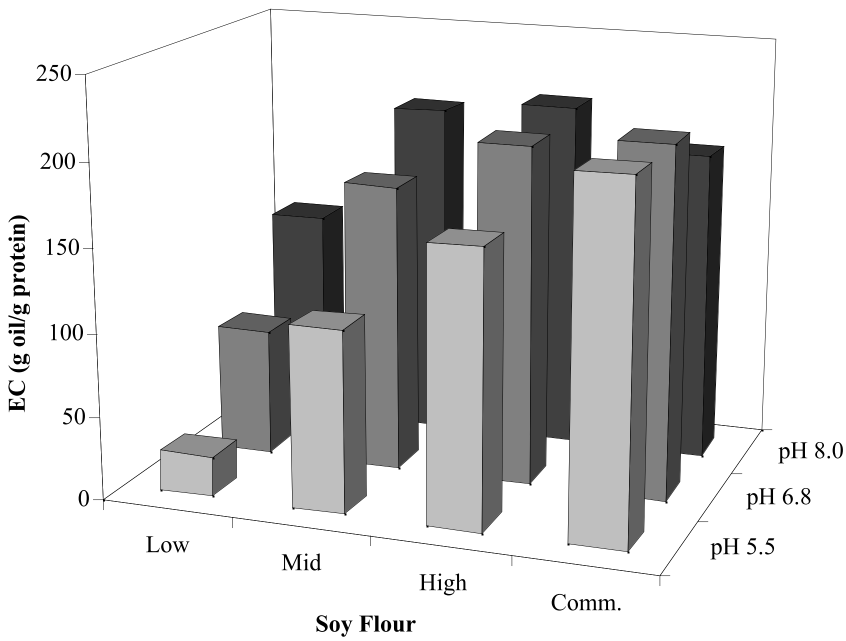


Figure 9.7. Emulsification capacity (EC) of various types of LFSF (Low, Mid, and High PDI/RO) compared with DFSF (commercial defatted soy flour, designated as Comm.) at different pH conditions (8).

foam stabilities. DFSF produced very stable foams, with symmetrical, evenly distributed foam bubbles. As with WHC and FBC capacity, foaming properties of LFSF may be dependent not only on the PDI of the flour but also on RO content.

Functionalities of E-E Flours Produced from Value-Enhanced Soybeans

Heywood *et al.* (12) also studied the functional properties (protein solubility, emulsification characteristics, foaming characteristics WHC, and FBC) of the E-E soy flours produced from six varieties of value-enhanced soybeans. These soybeans included high-sucrose or low-stachyose (LSt), high-cysteine (Hc), low-linolenic (LLL), low-saturated-fatty-acids (Ls), high-oleic (Ho), lipoxygenase-null (LOX), and two commodity soybeans (Wc and St).

The soy flours varied in PDI (32.0–49.5) and RO content (7.0–11.7%). As expected, there were no significant differences for WHC, FBC, emulsification activity, or emulsification stability among E-E flours prepared from different types of beans. However, the flour characteristics or oxidative stability of these protein products may be different. In general, the PDI and RO values of E-E soy flours had greater influence on protein functionality than seed type did.

Applications of E-E Soy Meal or Flour

E-E Flour in Doughnuts

Defatted soy flour has been used in commercial doughnut mixes (13). The primary purpose of adding soy flour is to decrease the amount of oil absorbed by doughnuts during frying (14). Soy flour also improves gas retention and controls crust color and volume (15). Typical usage level of soy flour in commercial doughnut mix ranges from 1 to 3% of the total wheat flour in the formulation (16). However, there have been studies of the potential of using larger amounts of soy flour to reduce costs (17,18). Most of these efforts involved DFSF in standard cake doughnuts.

Effects of LFSF incorporation on compositional, physical, and sensory attributes of standard cake doughnuts were investigated (Heywood *et al.*, unpublished data). Low, mid, and high PDI/RO (18.2/6.5, 44.9/7.1, and 67.8/11.8, respectively) were compared with a commercially available DFSF (PDI/RO 73.0/0.6). These soy flours were added to the doughnut formulation at 3, 5, and 8% (wheat flour weight basis). LFSF maintained quality and sensory characteristics when added to standard cake doughnuts. However, LFSF did not behave as consistently and predictably as DFSF did. Furthermore, LFSF was not as effective in reducing fat absorption as was DFSF. Sensory panels found that type of flour and addition level both play integral roles in their responses for oiliness, darkness, tenderness, and moistness.

Texturized Soy Protein (TSP) Production from E-E Flour

Extruders are used to produce meat analogs or extenders from plant proteins. TSP is produced primarily by extruding defatted soy flour, soy protein concentrate, and occasionally, soy protein isolate. The exposure of proteins to high temperature, pressure, and mechanical shear in the extruder causes proteins to align parallel to the extruder barrel, and expand when forced through the die. The sudden pressure decrease as the extrudate leaves the die causes water to flash off as steam, resulting in an expanded, porous structure. Riaz's research group at Texas A&M University produced TSP using partially defatted E-E products (19). E-E meal was adjusted to 21% moisture content, and extruded shreds or chunks were obtained by a secondary extruder. These products hydrated readily, resembled ground or chunk meat, and retained a chewy texture when cooked. It was found that an E-E protein product with PDI as low as 25 could be satisfactorily texturized.

Crowe and Johnson (20) studied the effects of PDI and RO content of E-E soy flour on texturizing soy protein and on functionality of the resulting TSP products. Ten partially defatted soy flours with RO contents and PDI values ranging from 5.5 to 12.7% and 35.3 to 69.1, respectively, were texturized by using a twin-screw extruder. The TSP products, including a commercial sample (from Archer Daniels Midland), were tested for WHC and texture of the hydrated TSP. TSP-extended ground beef was evaluated for its sensory quality.

WHCs, bulk densities, and sensory quality of TSS produced from partially defatted soy flour were evaluated. RO content tended to negatively correlate with WHC. WHC negatively correlated with bulk density. Similarly, Rhee *et al.* (21) reported an inverse relationship between WHC and bulk density in extrudates produced from flours with a wide range of nitrogen solubilities. The lack of available water-binding sites made these low-solubility or insoluble protein aggregates unable to incorporate sufficient water to develop proper dough consistency within the extruder barrel. Upon release from the die, the extrudate did not properly expand due to insufficient entrapped moisture as evidenced by decreased bulk density. The bulk density range of partially defatted soy flour extrudates was 0.22–0.26 g/cm^3.

Hardness of the TSP was significantly reduced in high-RO samples. The negative correlation between RO and all instrumental texture measurements indicated that the higher lipid contents of these samples may inhibit protein interactions responsible for desirable extrudate textural attributes. Both Faubion and Hoseney (22) and Bhattacharya and Hanna (23) found that removing lipids from flours favorably influenced TSP textural qualities, and Kearns *et al.* (24) reported a maximum recommended fat level of 6.5% in raw materials. However, neither PDI value nor RO content affected textural attributes measured in the TSP-extended ground beef system.

Sensory evaluation of TSP-extended ground beef patties indicated that there were no significant differences in hardness or chewiness in the TSP-extended ground beef compared with the control. RO content of partially defatted soy flour strongly correlated with overall flavor. In general, TSP from low-fat, partially defatted soy flour had less soy flavor and better overall flavor compared with TSP from high-fat, partially defatted soy flour.

TSP from Genetically Enhanced Soybeans and Application as Meat Extender

TSP made from soy flours (as described in the previous section, with PDI and RO values ranging from 32.0 to 49.5 and from 7.0 to 11.7%, respectively) of six different varieties of value-enhanced soybeans and two varieties of commodity soybeans were incorporated at the 30% level (rehydrated) into all-beef patties by Heywood *et al.* (25). The value-enhanced varieties included Hc, LLL, LOX, LSt, Ls, and Ho; the two commodity soybeans were Wc and St.

The bulk densities and WHC of the TSPs made with different value-enhanced soybeans were negatively correlated (r = –0.68). Moisture content of cooked beef patties ranged from 51.6 to 55.0%, well within the range of other published cooked moisture values (26). Fat levels of all patties varied little, ranging from 16.5 to 17.9%. Protein contents of the cooked patties were also very consistent, with little deviation from 21%.

Cooking parameters (moisture retention, fat retention, cooking yields) and selected texture attributes were also examined. Texture profile analysis showed that the addition of TSP increased hardness of the ground beef patty. TSP-extended beef patties had lower springiness values compared with those of the all-beef control. For sensory evaluation, panelists detected more soy flavor in all TSP-extended patties compared with the control. However, soy flavor did not deviate significantly between varieties. Finally, chewiness and juiciness scores were not significantly different among TSP-extended patties and the control. Even though instrumental analyses demonstrated some differences between TSP-extended patties and the all-beef control, human subjects did not detect significant difference.

E-E Meal Used as Animal Feed

The majority of E-E meal is currently incorporated into livestock feeds. There are different quality requirements when the protein meal is fed to ruminant animals than when it is fed to non-ruminant animals. Antinutritional factors are of primary concern for non-ruminant animals, whereas the rumen-bypass protein content is the most important quality indicator for ruminant animals.

Compared with SE soy meal, E-E meal has higher oil content and thus contains more energy. Woodworth *et al.* (27) studied amino acid digestibility and digestible energy (DE) and metabolizable energy (ME) of E-E and SE meals when fed to swine. The apparent ileal digestibility of crude protein, lysine, valine, isoleucine, and other amino acids were greater ($P < 0.05$) for the E-E product compared with the SE protein meal. Energy values had the same trend. The SE meal had lower DE and ME compared with those of E-E products. The nutrient compositions of the two products were similar on an equal dry-matter basis. There may be lower nutrient concentration in the animal waste when using E-E meal due to its higher digestibility. A similar study of starter pig feeding examined the effect of type of soybean meal on growth performance (28). Pigs fed with E-E protein diet performed similarly to those fed SE soybean meal with added oil; therefore, E-E meal can replace the conventional product without affecting growth performance.

For lactating dairy cows, soybean meals from different processing methods have different feed performances due to their differences in rumen-bypass or undigestible protein content. Although SE soybean meal has a favorable amino acid profile and high post-rumen protein digestibility, its rumen digestibility is high; thus, less protein passes through the rumen, and less is utilized by the cows (29). Heat treatment, such as roasting and extruding, reduces rumen protein degradation, thus increasing rumen-bypass protein. Socha (30) showed that cows fed extruded soybeans produced 6.6 lb/cow/day more milk than cows fed untreated SE meal or raw soybeans. The quality survey conducted by Wang and Johnson (4) indicated that on average, SE and E-E meals had similar rumen-bypass protein.

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